Reaching for the Middle Strat and Lower Trop for AIRS CO_2 (progress toward satellite retrieval of a profile)

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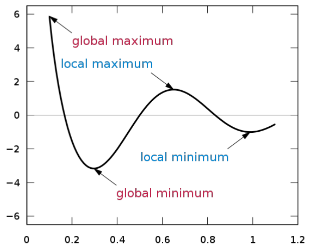
AIRS Science Team Meeting
April 26 - 28, 2011
Pasadena, CA

The Method of Vanishing Partial Derivatives Finding the LOCAL minimum on an N-Dimensional Surface According to Gauss

The CO_2 retrieval is a post-processing algorithm applied after AIRS Level-2 product generation:

Local Minimum: $\Theta_M,\ T^0(p),\ q^0(p),\ O_3^0(p),\ E_s^0(v)$



$$G^{(n)}(\mathbf{X}) = \sum_{v}\left[\Theta_M(\mathbf{X},v) - \Theta_C^{(n)}(\mathbf{X},v)\right]^2$$

$$\frac{\partial G}{\partial X_{CO_2}} \to 0$$

$$\frac{\partial G}{\partial X_{T(p)}} \to 0$$

$$\frac{\partial G}{\partial X_q} \to 0$$

$$\frac{\partial G}{\partial X_{O_3}} \to 0$$

$$\frac{\partial G}{\partial X_{E_s}} \to 0$$

Satisfying the partial derivatives individually provides the necessary and sufficient condition for an *extremum* of *G*(X). Ascertaining that the extremum is a local *minimum* is the result of requiring that G decreases monotonically with each iteration.

Caveats:

- **X(i) are assumed to be independent variables (within local extremum)**
- **the completeness of the variable set (channels chosen to avoid influence of other trace gases)**
- **the minimum found is local, not global (so the initial temperature must not be bad)**
- **the non-commutative averaging of variations of the variables within data pixels does not lead to significant errors (results of early testing in mid-trop support this)**

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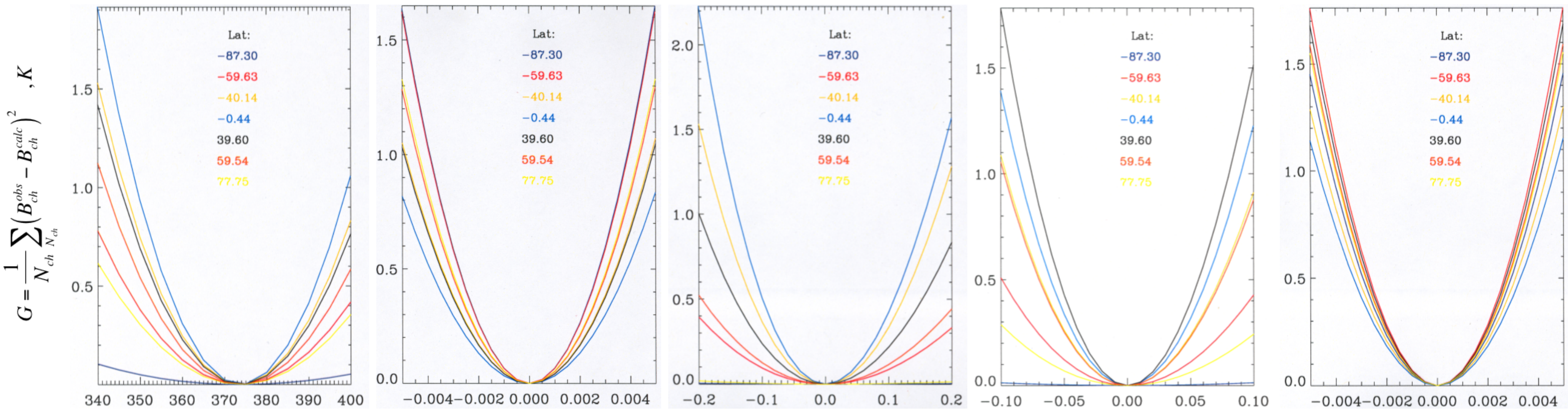
The Local Minimum is Well Defined for Acceptable Retrievals

But its sharpness does vary over the globe …



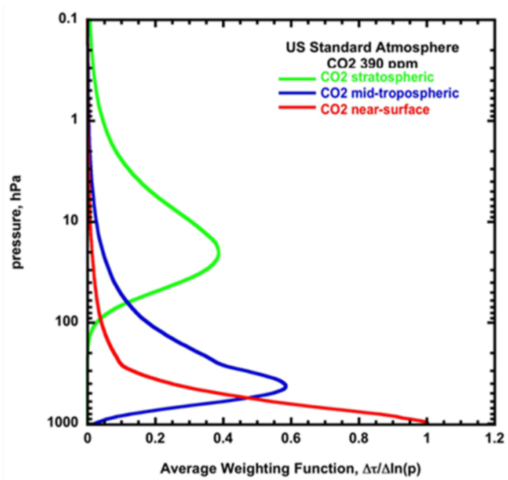
CO_2 (ppm) | **Air Temperature Fractional Change** | **Water Vapor Fractional Change** | **Ozone Fractional Change** | **Surface Emission, E_s Fractional Change**

Reference: M. Chahine, C. Barnet, E. T. Olsen, L. Chen and E. Maddy (2005) "On the Determination of Atmospheric Minor Gases from the Residuals of the Solution of the Radiative Transfer Equation". Geophys. Res. Lett., 32, doi: 10.1029/2005GL024165.

Factors Affecting the CO_2 Retrievals

	Mid-Troposphere -*10km*	Stratosphere – *30km*	Lower Trop – *2.2km*
ν range:	13 CO_2 channels: 700 cm^{-1} – 722 cm^{-1}	17 CO_2 channels: 650 cm^{-1} – 680 cm^{-1}	10 CO_2 channels: 730 cm^{-1} – 745 cm^{-1}
$T(p)$	Strong	Very strong	Strong
O_3	Strong	Weak	Medium
H_2O	Medium	No impact	Medium
Surface emission, E_s (T_s, ε_s)	Very weak	No impact	Medium
$\Delta G/\Delta CO_2$*	~0.4	~0.2	~0.5

*($\Delta G/\Delta CO_2$) describes the sensitivity of observed spectra to changes in CO_2. It is a function of the lapse rate of atmospheric temperature profiles which is 7 K/km in the mid-troposphere, 1.5K/km in the stratosphere and 10K/km near surface.

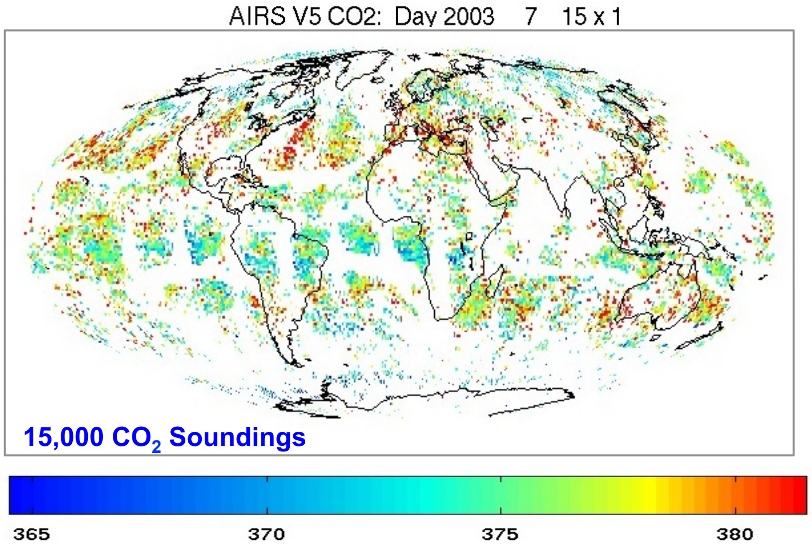


- Mid-troposphere: Operational and Released to the Public (Sept 2002 – Present)
- Stratosphere: Algorithm Completed, QA and Validation Underway
- Lower troposphere: Algorithm Nearly Complete, Preliminary Retrievals Underway

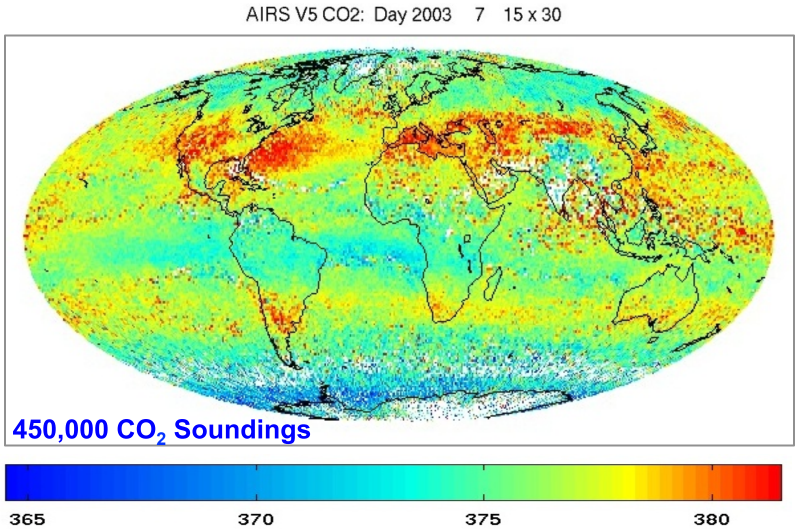
AIRS Operational Product
Mid-Tropospheric CO_2
(8-10km)

Global Yield of AIRS Level 2 Mid-Tropospheric CO_2

AIRS Daily CO_2 Yield
1°x1° Spatial Resolution



AIRS Monthly CO_2 Yield
1°x1° Spatial Resolution



AIRS Level 2 Mid-Tropospheric CO_2 retrieval yield is controlled by requirement for highest quality temperature and water vapor AIRS Level 2 products in 2x2 array of adjacent FOVs

Yield is expected to increase when optimized to be compatible with V6

Day/Night, Pole-to-Pole, Land/Ocean/Ice, Cloudy/Clear

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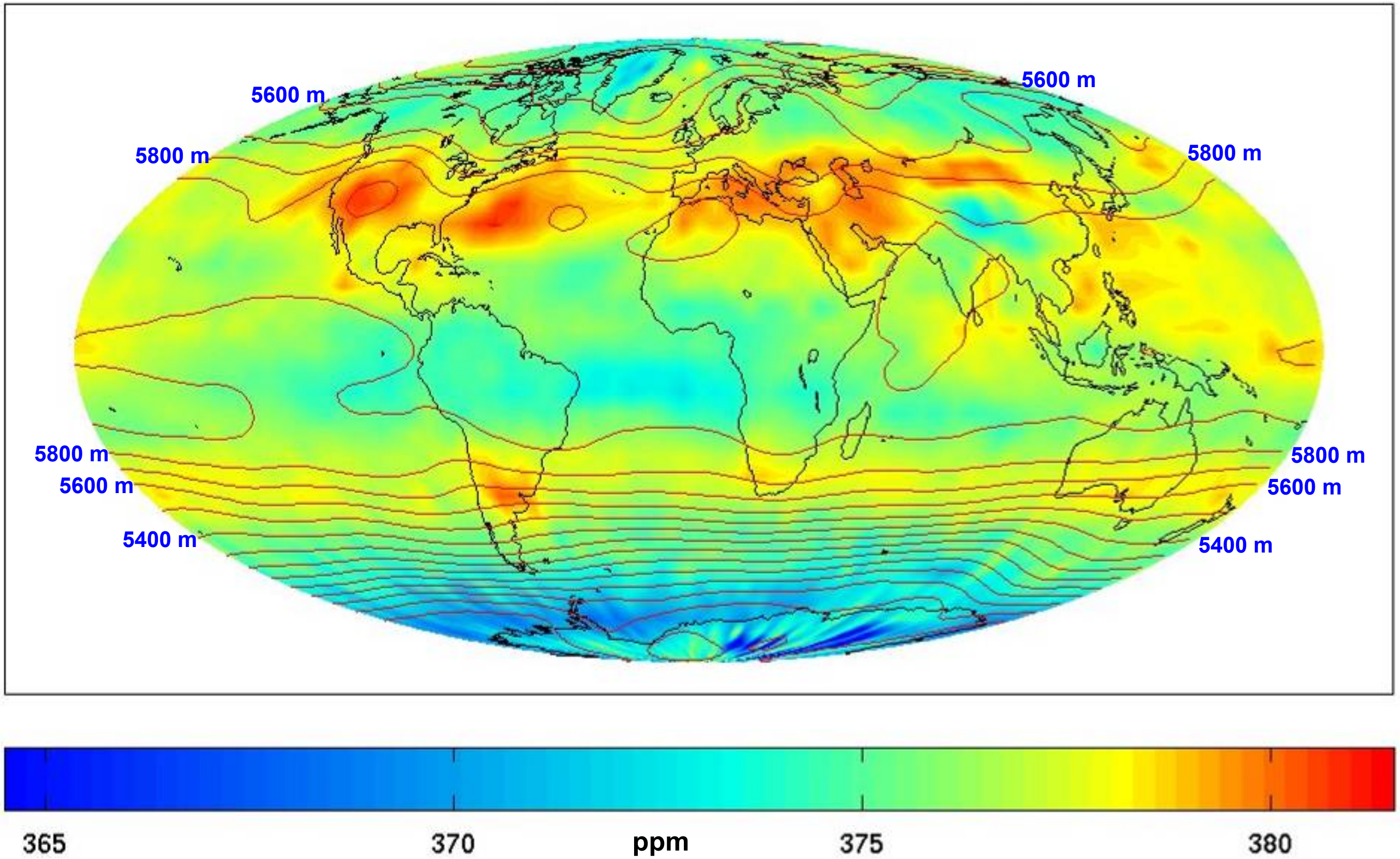
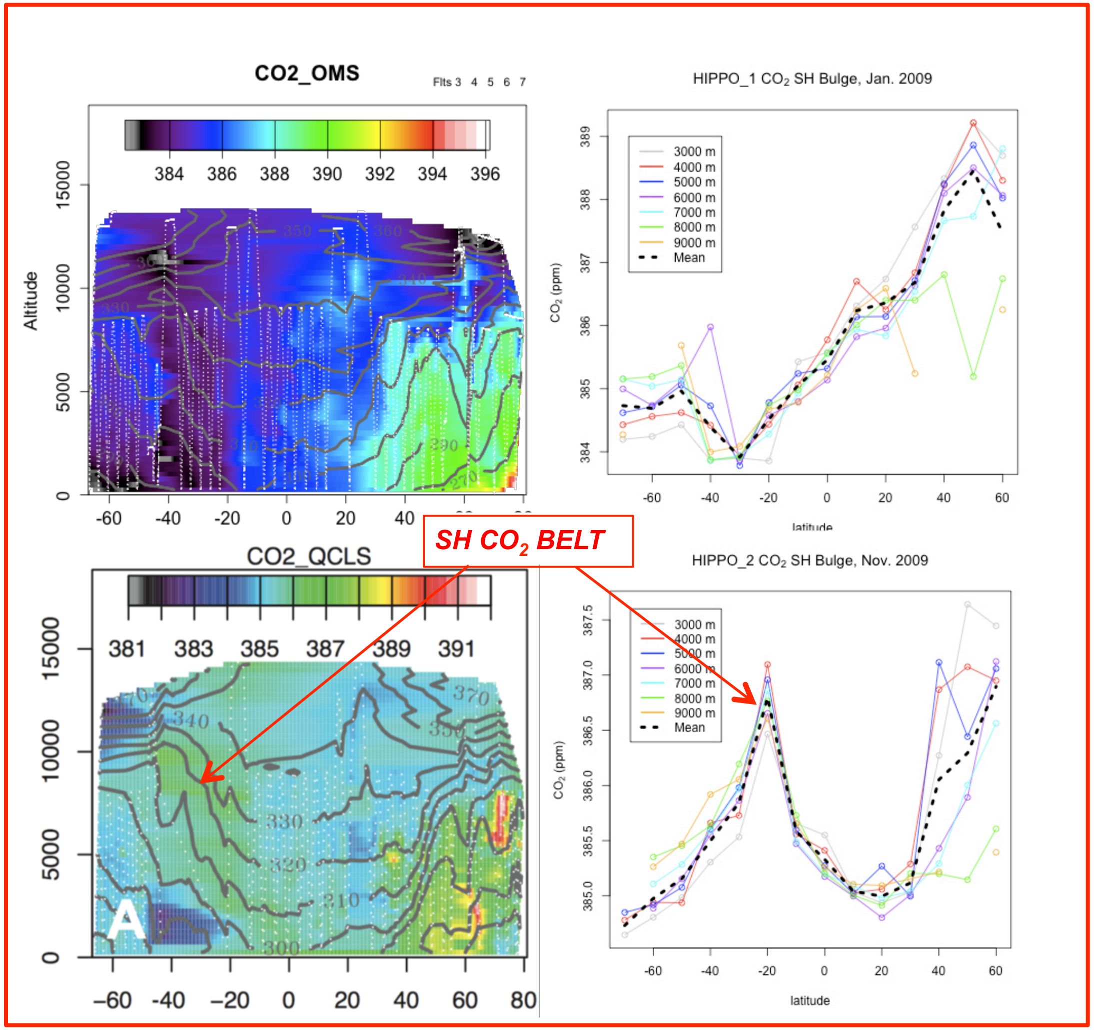
AIRS Data Show
CO_2 is not well mixed in Mid-Troposphere

July 2003 AIRS mid trop CO_2 (5° smoothing) with 500 hPa gph contours

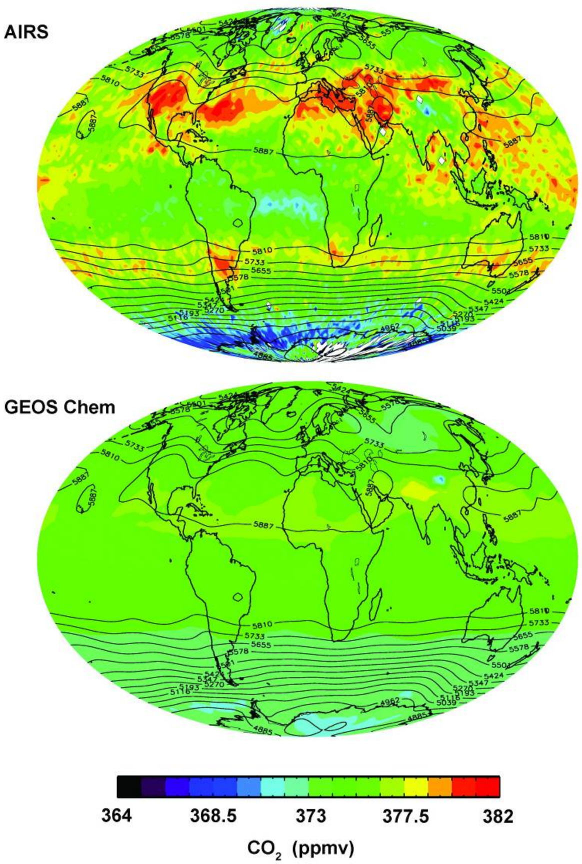


CO_2 is NOT Well Mixed in the mid-troposphere
- **Driven by synoptic-scale phenomena (polar/subtropical jet streams)**
- **Complexity of the Southern Hemisphere not present in models**
- **AIRS mid-trop data will facilitate modeling of vertical & horizontal transport**

Variability seen in 2009 HIPPO Campaign Compares well with AIRS



AIRS has observed a seasonally-variable SH CO_2 Belt Since 2003



S.C. Wofsy, *et al* (2011), HIAPER Pole-to-Pole Observations (HIPPO): Fine grained, global scale measurements of climatically important atmospheric gases and aerosols, *Proceedings of the Royal Society A, in press.*

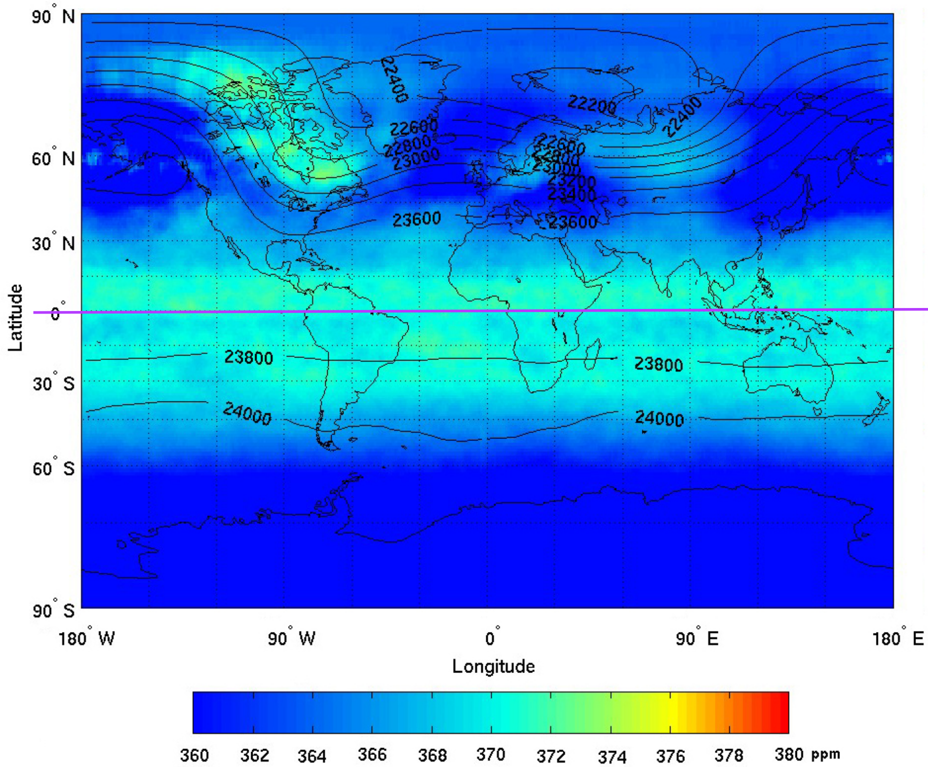
M.T. Chahine, et al,, Satellite remote sounding of mid-tropospheric CO2, Geophys. Res. Lett., 35, L17807, doi:10.1029/2008GL035022.

AIRS Developing Product
Mid-Stratospheric CO_2
(25km)

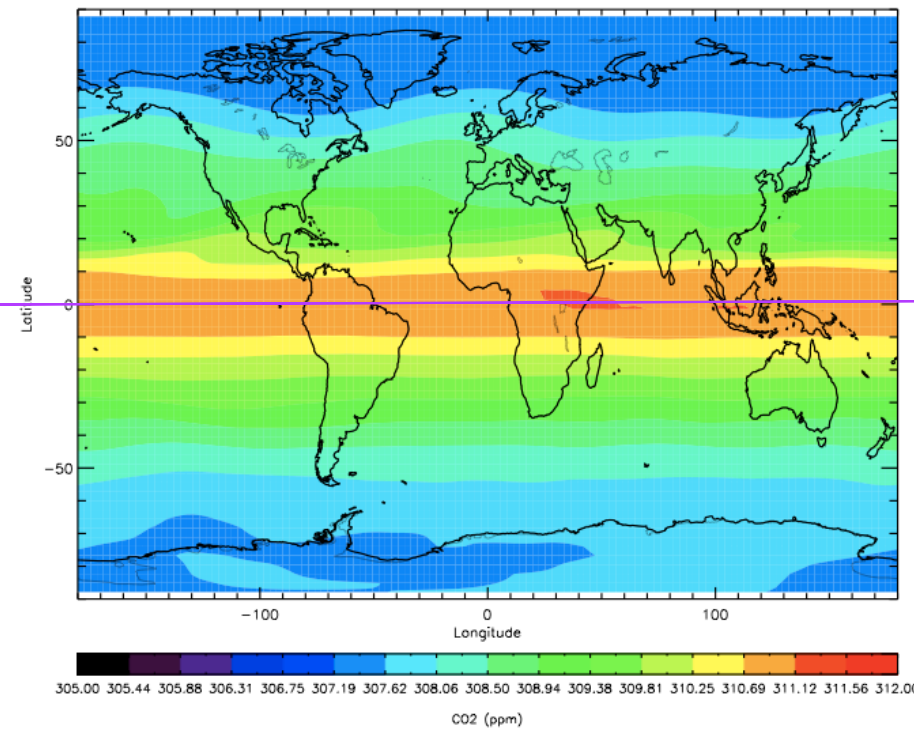
Jan 2003 Stratospheric CO_2 Retrieval Compared to Models

(AIRS Stratospheric Contribution Function Applied to Models)

AIRS Retrieved CO_2



3-D IMATCH CO_2



360 **Contours are 30 hPa GPH** **380**

305 **Model profile weighted by AIRS sensitivity function** **312**

PRELIMINARY

Both AIRS and models show presence of tropical pipe

- **AIRS shows greater variation with latitude (~15 ppm vs ~4 ppm)**
- **AIRS shows additional troposphere intrusion at high latitude**

Model Runs by Xun Jiang, University of Houston

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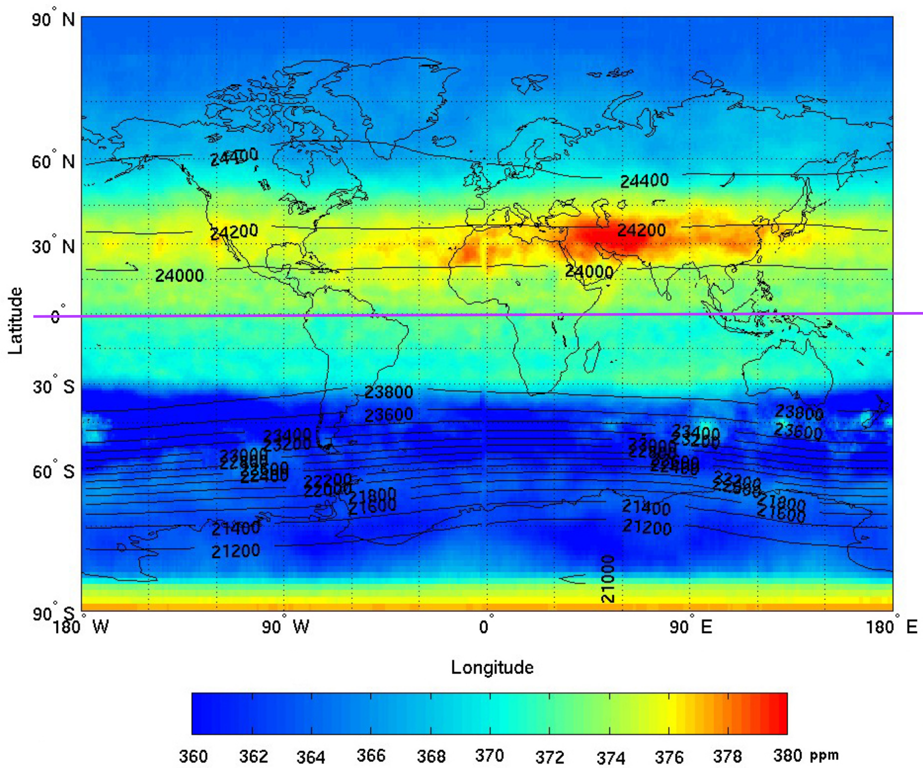
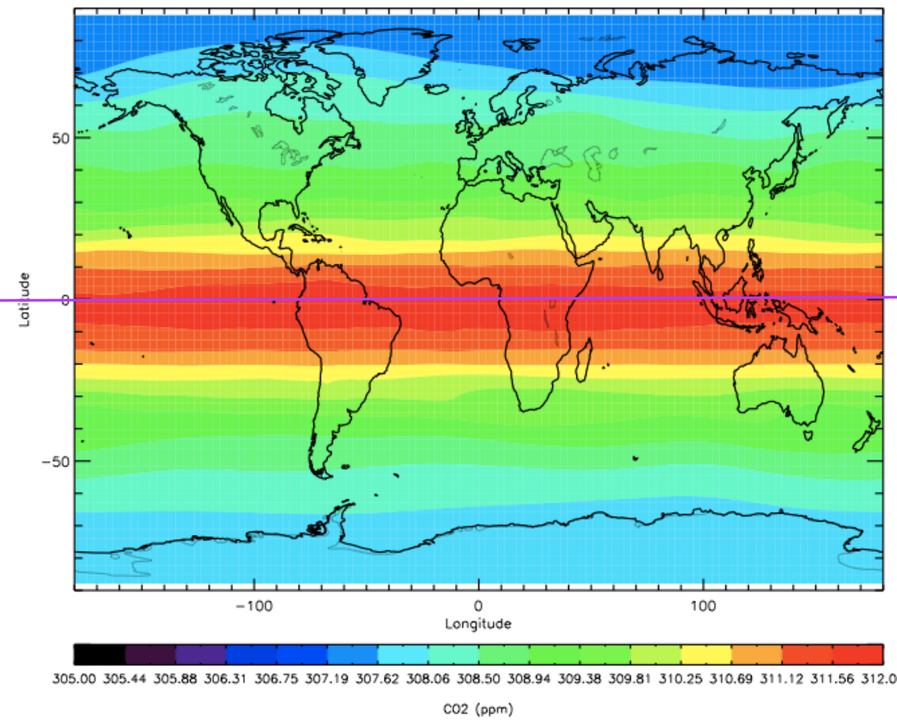
Jul 2003 Stratospheric CO_2 Retrieval Compared to Models

(AIRS Stratospheric Contribution Function Applied to Models)

AIRS Retrieved CO_2



3-D IMATCH CO_2



360 **Contours are 30 hPa GPH** **380**

305 **Model profile weighted by AIRS sensitivity function** **312**

PRELIMINARY

AIRS tropical Pipe shifts northward in July whereas model tropical pipe remains unchanged
- **AIRS shows greater variation with latitude (~15 ppm vs ~4 ppm)**

Model Runs by Xun Jiang, University of Houston

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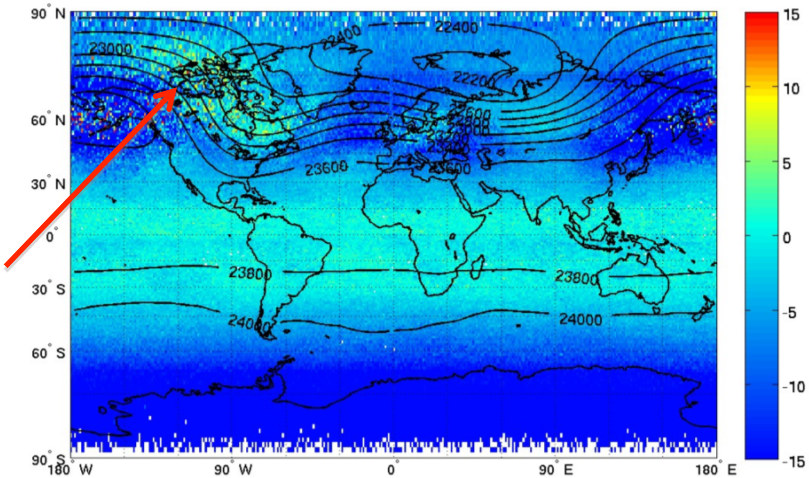
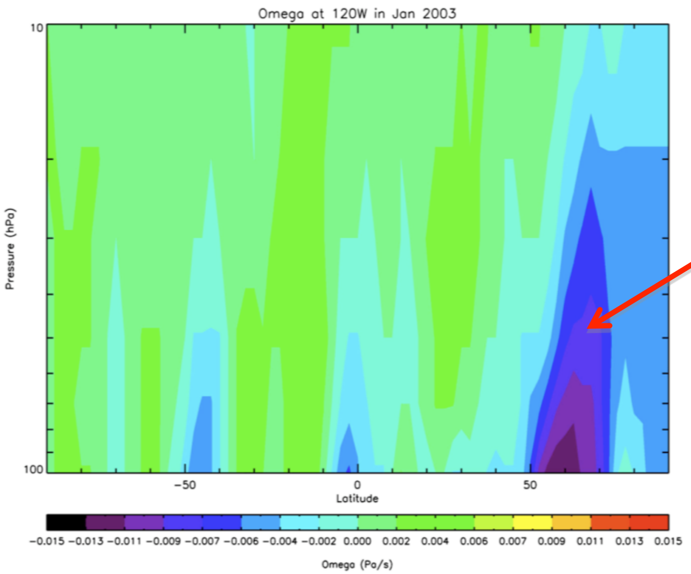
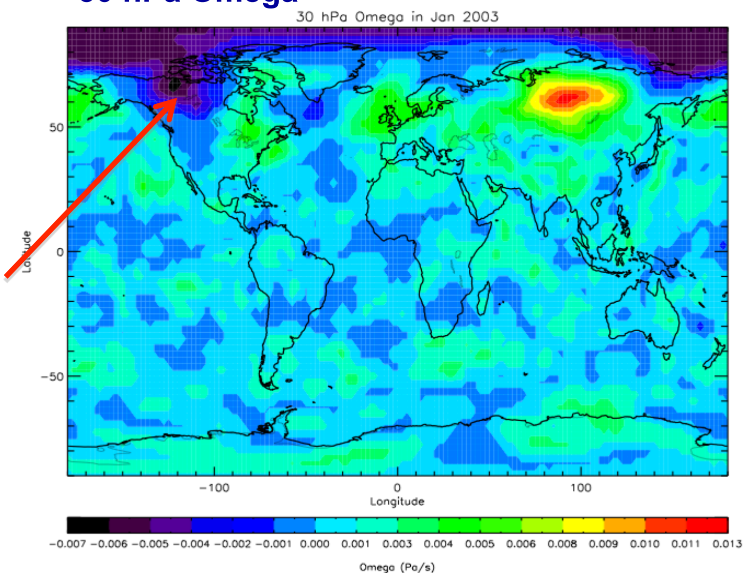
AIRS Stratospheric CO_2 (tropospheric CO2 intrusion/vertical wind)

AIRS CO2 for January, 2003





30 hPa Omega



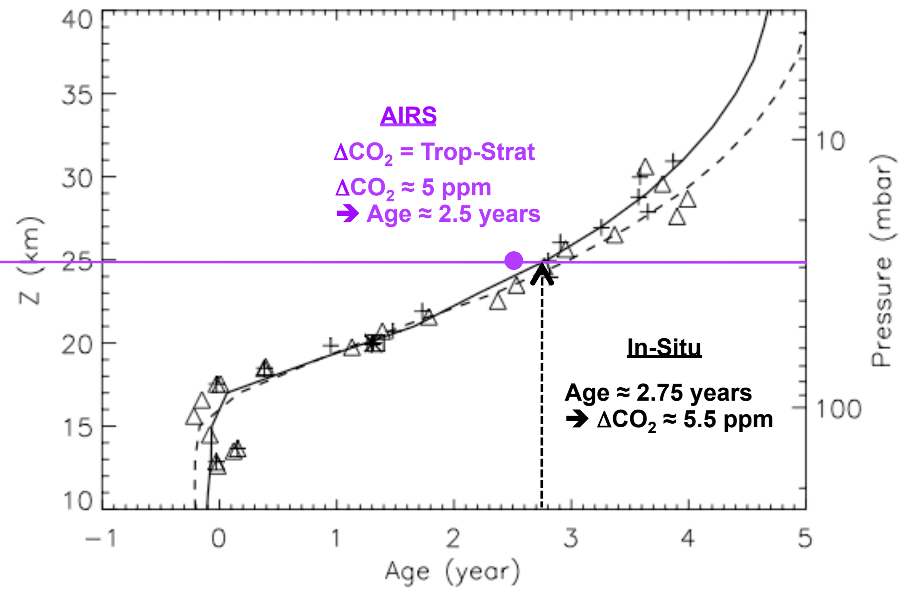
Vertical velocity (dP/dt) at 120°W in January 2003 (NCEP2 Reanalysis)
Negative (positive) value represents upward (downward) motion. Units are Pa/s.

Omega = dP/dt at 30 hPa (NCEP2 Reanalysis)
Negative Omega --- Upward motion;
Positive Omega --- Downward motion

CO_2 Trop-Strat Contrast due to Age of Stratospheric Air

Hall et al (1999), Evaluation of transport in stratospheric models, JGR., 104, 18815

Altitude of maximum of
AIRS Contribution Function



**Age of stratospheric air vs altitude
for |latitude| ≤ 10°**

The concentration of CO_2 in the stratosphere will be lower than in the troposphere by ~ 2 ppm for each year it lags behind due to interannual growth of tropospheric CO_2

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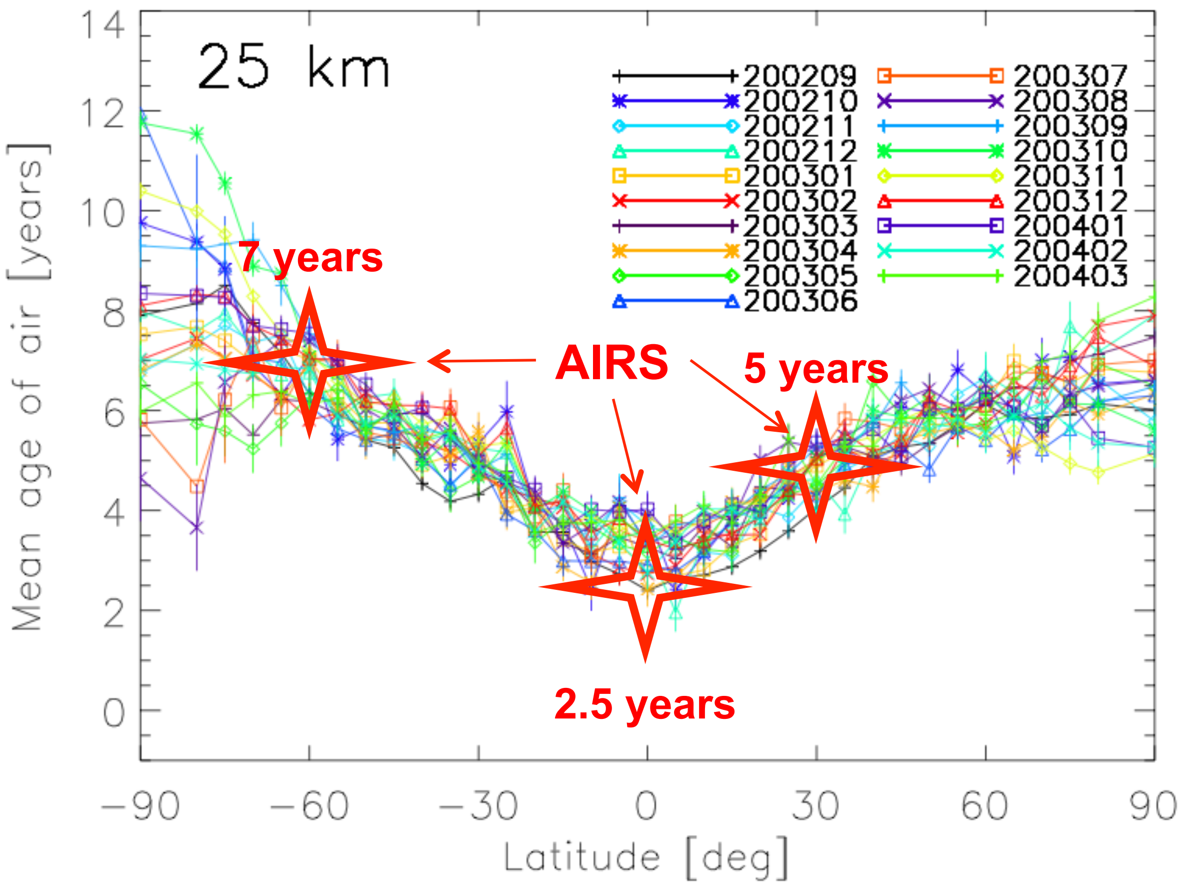
Age of Stratospheric Air for Jan 2003 AIRS CO_2 Contrast Agrees with that Determined by MIPAS SF_6 Measurements

The concentration of CO_2 in the stratosphere will be lower than in the equatorial troposphere by ~ 2 ppm for each year it lags behind due to interannual growth of tropospheric CO_2



MIPAS SF_6 Measurements
Monthly zonal means
Sept 2002 through Mar 2004

Stiller et al (2007), Global distribution of mean age of stratospheric air from MIPAS SF6 measurements, Atmos.Chem.Phys.Discuss., 7,13653

Age of stratospheric air vs latitude at 25 km altitude

- **AIRS CO_2 retrievals agree with MIPAS SF_6 measurements, which confirms asymmetry**

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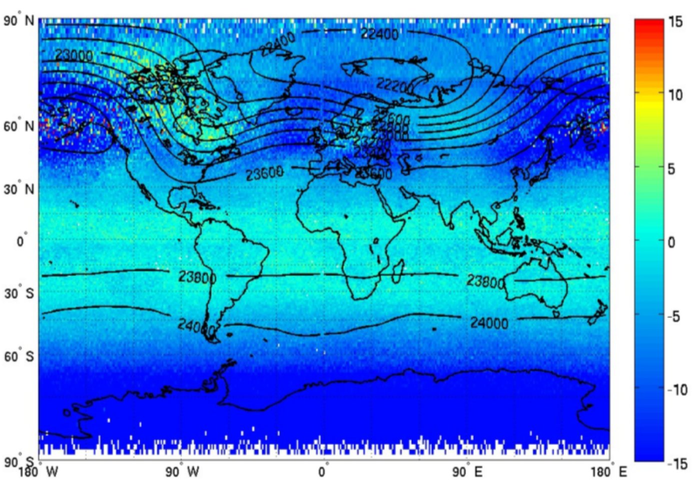
Stratospheric CO_2 Variation with Latitude
(CO_2 after subtracting <CO_2> for |lat| ≤ 4 °)

Equator to Pole Contrast

- **Models show much lower contrast than AIRS and in-situ measurements**

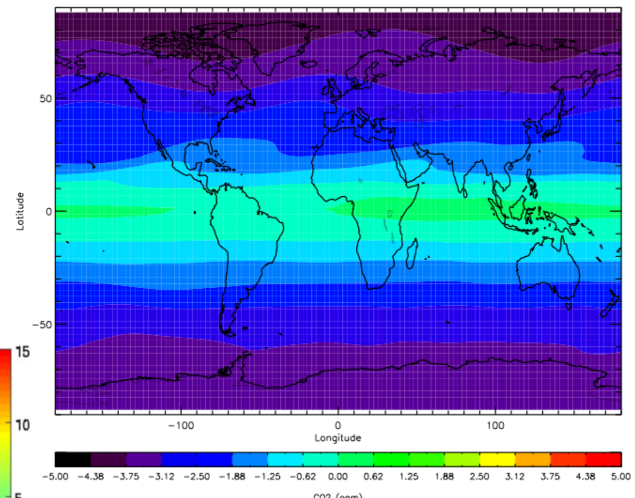
AIRS



Color Bar Range : -15 to + 15 ppm

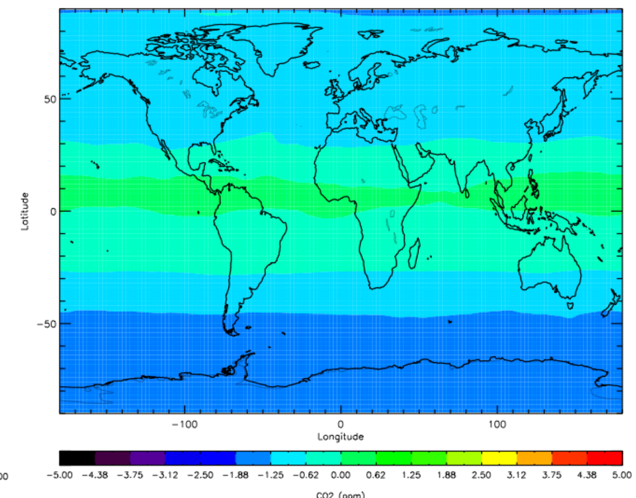
Range of Observed Variations: -10 to +5 ppm

3-D IMATCH



Range of Variations: -5 to +2 ppm

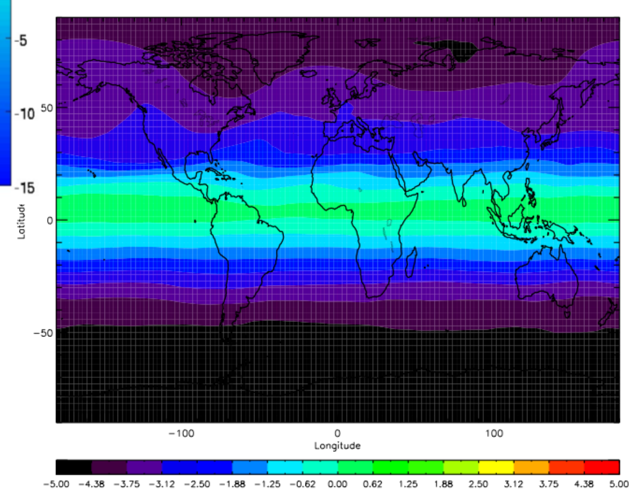
3-D GEOS-Chem



Range of Variations: -2 to +2 ppm

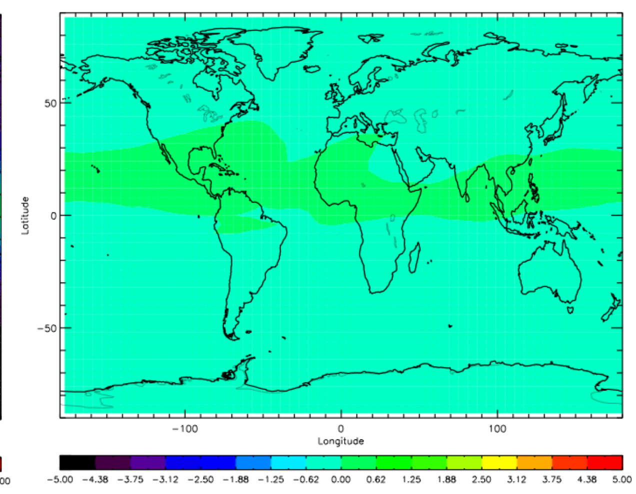
Color Bar Range: -5 to +5 ppm

3-D MOZART-2



Range of Variations: -5 to +2 ppm

3-D Carbon Tracker



Range of Variations: -1 to +2 ppm

AIRS First Results
Lower-Tropospheric CO_2
(2.2km)

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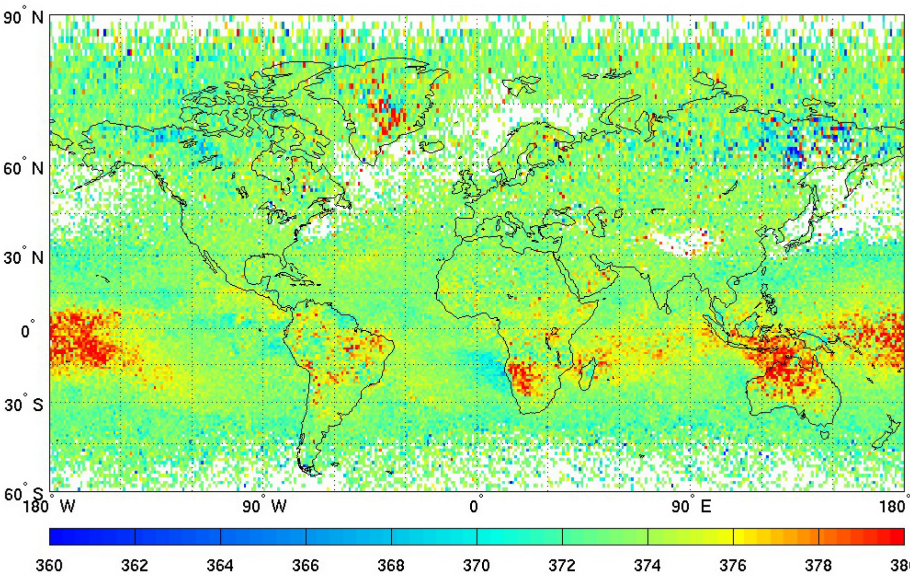
AIRS Lower-Tropospheric (2.2km) CO_2

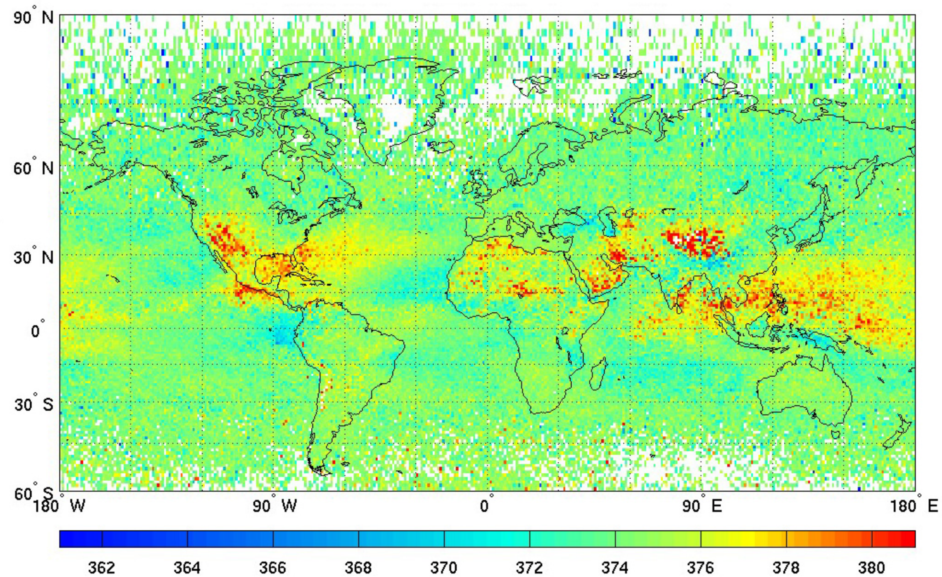
(preliminary results – channel set not yet optimized and surface emission module not yet implemented)

January 2003
AIRS Lower Tropospheric CO2 Retrievals



PRELIMINARY

July 2003
AIRS Lower Tropospheric CO2 Retrievals



PRELIMINARY

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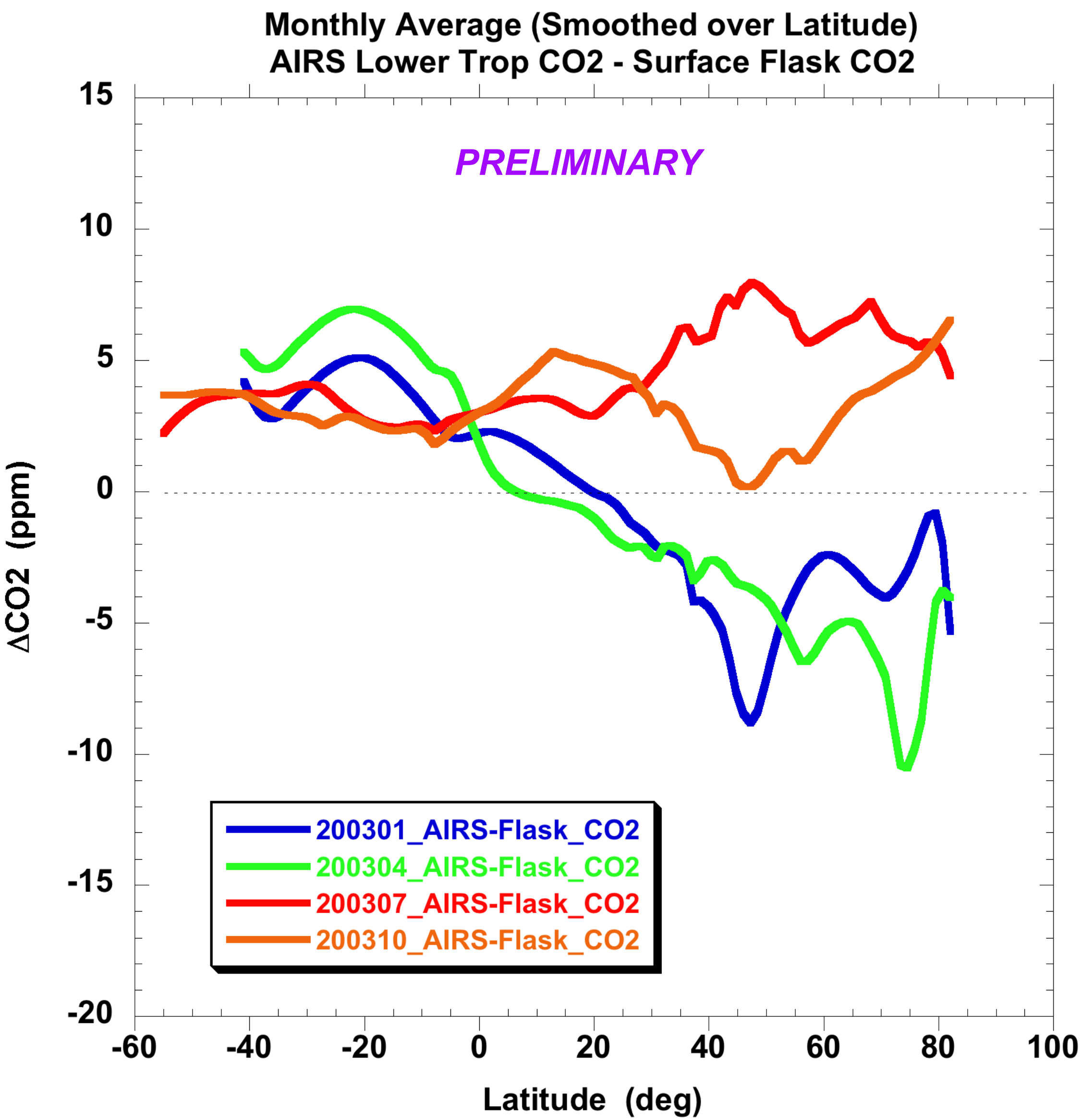
Prelim AIRS Lower-Tropospheric (2.2km) CO_2

(comparison to collocated surface flask locations)

(Flask monthly averages; monthly average and std dev for AIRS retrievals within 250km)



Latitude dependence of seasonal variation of (AIRS-Flask) appears reasonable:

Strong NH seasonal variation apparent
- **Respiration at surface greatest Jan-Apr**
- **Vegetative drawdown at surface greatest Jul-Oct**

When calculation of lower troposphere averaging kernels for AIRS retrievals are implemented, analysis comparison to aircraft profiles will be carried out

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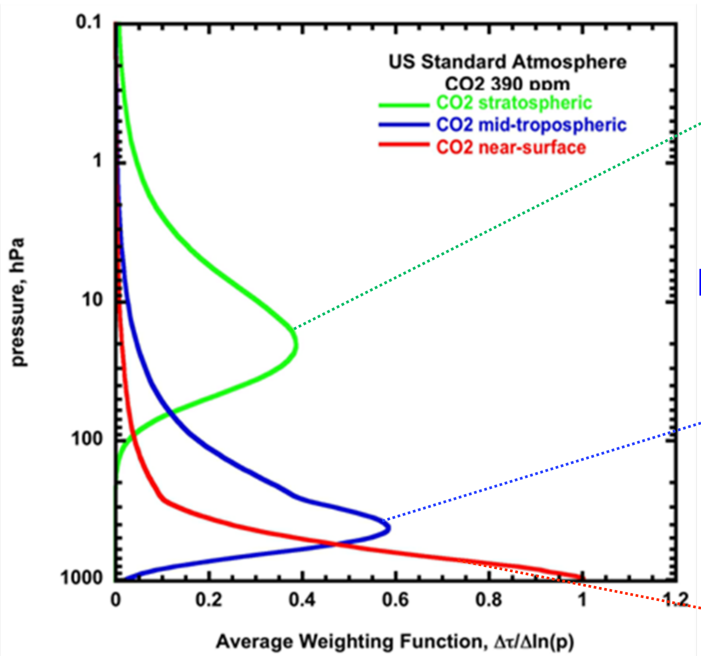
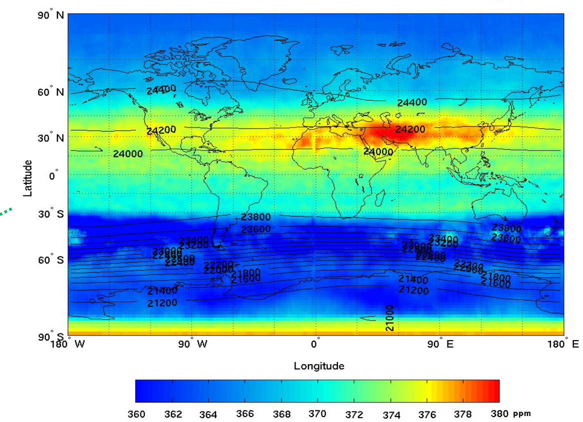
3 Layers of CO_2 Derived from AIRS July 2003

AIRS CO2 Weighting Functions



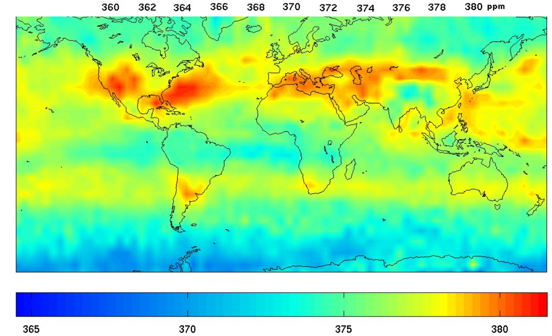
Sensitivity of AIRS Channels to CO2

Stratosphere



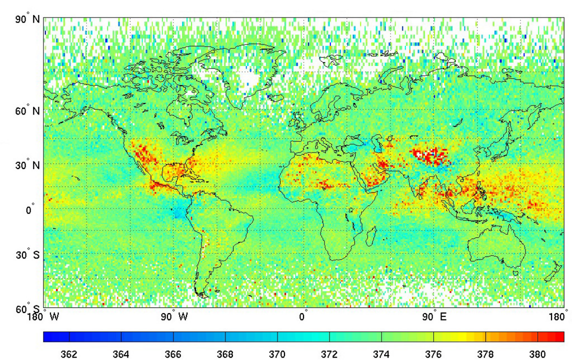
Preliminary

Mid-Troposphere



Validated
Sept 02 - Present

Lower Trop



Preliminary

M. Chahine et. al. (JPL)

Moustafa T. Chahine
1935 - 2011